DISTRIBUTIONAL STUDY OF THE ZION SNAIL, *PHYSA ZIONIS*, ZION NATIONAL PARK, UTAH

David Ng[1,2] and James R. Barnes[1]

ABSTRACT.—The major hanging gardens and associated water seeps in Zion National Park were surveyed for the presence of the Zion Snail (*Physa zionis*). Environmental parameters, including water depth, water velocity, substrate slope, and algal cover, were measured to determine their effect on the local distribution of the snail. Large populations (densities 125 to 250/m^2) were found in the Virgin River Narrows area of the park and at a hanging garden and seep located 1.0 km north of Scout Lookout. Densities in other localities were low in comparison. Snails were not found in all hanging gardens or seeps. The major factor controlling within seep distribution was determined to be water velocity. Experiments were conducted to test the ability of the snail to remain attached during differing water flows. The snail showed an ability to remain attached during high flows, but few snails were found in areas of high flow.

The Zion Snail, *Physa* (*Petrophsa*) *zionis* Pilsbry (1926), an endemic to Zion National Park, Washington County, Utah, is found in water seeps and associated hanging gardens on the canyon walls along the Virgin River Narrows region of the park. The limpetlike characteristics of *P. zionis*, a reduced shell spire, enlarged last whorl, and large foot, were reported as being adaptations for attachment on vertical surfaces of seeps (Pilsbry 1926, Chamberlain and Jones 1929). There is no literature on the ecology or natural history of the Zion Snail other than the mention of a snail-algae association and the hypothesis that *P. zionis* evolved from a common *Physa* type (Woodbury 1933, Talmadge 1970).

The purposes of this study were: (1) to survey and determine the distribution and population density of the Zion Snail within Zion National Park, (2) to determine the importance of specific habitat variables which may limit snail distribution within seeps, and (3) to test the hypothesis that the limpetlike morphological adaptations provide the snail with greater substrate attachment abilities in the seep environment.

STUDY AREA

Zion National Park, in southwestern Utah, is in an area of sandstone formations cut by the Virgin River and its tributaries. Seeps and hanging gardens that offer suitable habitat for the Zion Snail are found at the junction of the Navajo and Kayenta sandstone layers. Seeps are formed when water percolating through the porous Navajo layer contacts the impervious underlying Kayenta formation and flows laterally to the canyon walls (Welsh and Toft 1981). The Navajo-Kayenta junction is at different elevations along the canyon wall in relation to the Virgin River. In the Main Canyon area of the park, the river has cut the deepest and seeps are farthest removed from the river. In the Narrows the river is near the Navajo-Kayenta junction elevation, and many of the seeps are close to the river. Malanson (1978, and 1980) describes the plant communities for some hanging gardens in the Narrows region.

Seeps in Zion National Park are located in three regions. They are the Narrows, the Gateway to the Narrows, and Main Canyon. The Narrows, including Orderville Canyon, is a narrow box canyon where vertical canyon walls form the channel of the Virgin River. The canyon walls are less than 10 m apart in some areas. Seeps in the Narrows are mainly simple dripline and window-blind types (Welsh and Toft 1981), though a few low alcoves have been carved out by the river. All seeps have varying amounts of calcium carbonate precipitate and algae. A film of water usually less than 1 mm in depth flows over the vertical and horizontal surfaces. Clinging herbaceous plants and mosses are common, indicating the presence of relatively stable or

[1]Department of Zoology, Brigham Young University, Provo, Utah 84602.
[2]Department of Zoology, University of Texas, Austin, Texas 78712.

TABLE 1. Classes of ecological parameters used to analyze local distributional patterns within seeps.

Parameters	Classes of parameters 1	2	3	4	5
Depth (mm)	0–1	2–3	4–10	>10	
Flow (mm)	<1	>1			
Slope (degrees)	0–10	11–45	>45		
Algae (% cover)	0–12.5	12.5–25	25–50	50–75	>75

old seeps (Malanson 1980). New flows without vegetation are also present.

The Gateway to the Narrows region, immediately downstream from the Narrows, is a more open area that receives heavy visitor use. The Gateway is approximately 1.5 km long, with a paved trail along the east canyon wall. Seeps in this section are large and of the window-blind and alcove types (Welsh and Toft 1981). Plant communities are well developed, with many herbaceous and woody plants present. Calcium carbonate precipitation is extensive, with deposits several centimeters in depth common. Seeps in this section are isolated from the Virgin River.

The Main Canyon, which extends downstream from the Gateway, widens considerably. Seeps and gardens are large alcoves, alcove-plunge basins, or terraces (Welsh and Toft 1981). Water flow in these seeps is generally high, with depths of several millimeters measured. Woody plants and pockets of soil are present in most seeps. Most seeps are connected to the Virgin River by small (< 2.0 m wide) streams with rock-gravel-sand substrates.

A terraced seep-spring area approximately 1 km north of Scout Lookout in the Main Canyon was used to study the ecological variables that may limit local distribution and attachment abilities of the snail. This seep is 10 m wide, with two small springs at the south end. The terraces receive surface flow from areas high on the canyon wall, whereas the springs feed into a small stream. The stream flows over a 5 m waterfall, is joined by flow from the terraces, and then flows for approximately 30 m into the Virgin River. Water temperature in the springs is relatively constant (19–21 C), but the terrace water temperature fluctuates with the ambient air temperature. Moss, algae, and herbaceous plants are present. The substrate varies from thick calcium carbonate deposits on the sandstone wall and terraces to the cobble-gravel-sand stream bottom. Water depth and velocity in the stream range from 0 to > 200 mm and 0 to > 1.0 m/sec, respectively.

METHODS

The major seeps in Main Canyon and Gateway to the Narrows were surveyed during the summers of 1981 and 1982. The Narrows was surveyed only in July 1982 because of the limited time it was accessible. The terraced seep-spring north of Scout Lookout in Main Canyon was sampled 24 October 1981 and 2 April, 24 April, 8 June, and 16 July 1982. Detailed quantitative work in the Gateway region was impractical because of heavy visitor use.

A quadrat (10 x 15 cm) was used to estimate population density. Four variables, including water depth, water velocity, substrate slope, and algal cover, were measured in each quadrat. Quadrats were placed every 30 cm apart along random transects across the water course. The number of transects and quadrats required to sample a seep or spring area varied with changes in the amount of flowing water. Water velocity (force of flow) was determined by measuring in millimeters the amount of water forced vertically into a piece of 2 mm diameter plastic tubing. Substrate slope was measured to the nearest 5 degrees. Snail size was measured to the nearest 0.5 mm in situ. Sampling was limited to seeps accessible without climbing equipment.

Statistical analysis of the measured variables was accomplished by using the Chi-square analysis program in MINITAB (Ryan et al. 1981) and the ANOVA program in RUMMAGE (Scott et al. 1982). For analysis, the measurements were divided into classes (Table 1).

To test the attachment ability of the snail, snails were subjected to various flows in a

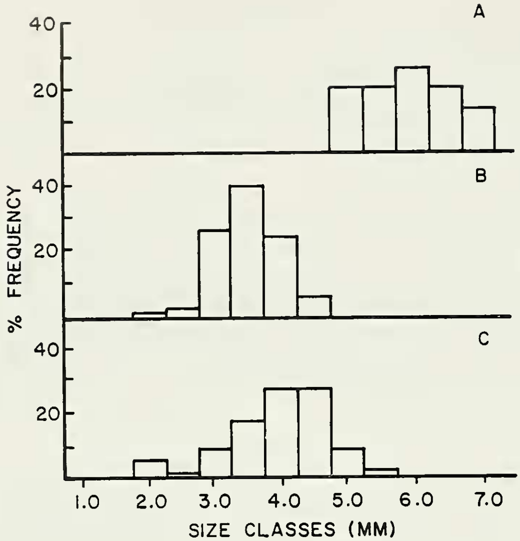

Fig. 1. Size distribution of the Zion Snail found in the Narrows area of Zion National Park. A and B are from seeps in the Main Narrows; C is from Orderville Canyon.

plastic channel and on natural substrate. In the plastic-channel test, snails were placed at the end of a 1 m long plexiglass channel in which water from the stream was channeled through in increasing amounts. In the natural-substrate wash experiment, two volumes of water (5 and 10 liters) were poured down a 15 cm wide plexiglass channel at 5 and 10 second duration onto snails in situ. The channel was held at 30 degrees. For comparison, the more common stream snail, *Physa gyrina*, was tested in the laboratory.

Results

Population Density and Distribution

Our surveys show the Zion Snail occurring from a seep-spring stream area 1 km north of Scout Lookout into Orderville Canyon. The Narrows area above Orderville Canyon was not surveyed in this study. Zion Snails were not found in seeps on the west side of the Virgin River nor south of the seep-spring stream area above Scout Lookout in the Main Canyon area.

Narrows.—Six seeps examined in this region contained snails. All snails were found in dripline or window-blind type seeps where vegetation was abundant. Many snails were observed less than 10 cm above the Virgin River. Snails were not found on the northwest canyon wall. Of the six seeps that contained snails, three were sampled quantitatively, two in the main part of the Narrows and one in Orderville Canyon. The first seep was 4 m wide, located approximately 0.3 km into the Narrows, and had a density of 30 snails/m^2. The second was 6 m wide, located 0.5 km into the Narrows, and had approximately 100 snails/m^2. The seep in Orderville Canyon is a long, continuous dripline with approximately 130 snails/m^2. The other three seeps that contained snails were in the main part of the Narrows. These seeps were all less than 3 m wide and had estimated densities of $<$ 20 snails/m^2. The largest snails, 6.5 to 7.0 mm in length, were found in the main Narrows. Average length ranged from 3.0 to 6.0 mm (Fig. 1). Based on the above densities, 3,000 snails is a conservative estimate of the minimum population in the Narrows region.

Gateway.—This area was only qualitatively sampled because the large number of park visitors using the trail made quantitative sampling impractical. Very few seeps contained snails, and even in large or continuous seeps the snails were found in discrete patches. Densities of 5 to 10 snails/m^2 were common, with 20 to 30 snails/m^2 maximum. Snail sizes throughout this area were 3 to 4 mm at the time of sampling.

Main Canyon.—The only snails found in the Main Canyon area were in a terraced seep-spring 1.0 km north of Scout Lookout. Three in-seep snail distributional patterns were evident: (1) on the terraces of the seep; (2) at the head of the northern-most spring; and (3) in the main stream below the waterfall down to the confluence with the Virgin River. Snails were not found in the southern spring. Densities ranged from 40/m^2 in the stream to more than 250/m^2 in the spring. However, because of the small surface area of the spring, the total number of snails there is less than 1,000. The highest densities were found in spring season with the appearance of young snails. In the terrace region the density was around 175/m^2. The size ranged from $<$ 1.0 mm (immatures) to 4.0 mm. Snails $>$ 5.0 mm were rare in this area. There was a marked decrease of snails $>$ 3.5 mm after June. The total population in this area apparently ranged from 2,000 to 6,000 snails.

TABLE 2. Results of natural substrate wash experiment using in situ *Physa zionis*.

Duration (Seconds)	Volume (Liters)	Rate of flow	Replicates	Number of snails Start	Finish	Percent remaining
5	5	1 l/sec	1	16	13	81.25
			2	11	8	72.72
			3	12	11	91.66
			4	13	11	84.62
	10	2 l/sec	1	10	10	100.00
			2	10	7	70.00
			3	10	7	70.00
			4	12	9	75.00
10	5	0.5 l/sec	1	12	12	100.00
			2	12	12	100.00
			3	13	7	53.85
			4	13	12	92.31
	10	1 l/sec	1	12	10	83.33
			2	11	9	81.81
			3	11	9	81.81
			4	14	12	85.71

Wash Experiments

In the preliminary plastic channel test, eight snails were used. At the initial flow of water through the channel, two snails were lost; the others remained attached up to flows of 280 mm in the measuring tube, the maximum achievable using water available in the field. Size did not appear to be a factor in attachment ability, since the largest (5 mm) and the smallest (1.5 mm) were among those remaining.

In the natural-substrate wash experiment, 78% of the snails remained attached after the highest flow (10 liters for 5 sec = 2 l/sec), and 86% remained after the lowest flow (5 liters for 10 sec = 0.5 l/sec). With flows of 1 l/sec, 83% remained after 5 and 10 sec. durations (Table 2). Snails became detached when the carbonate or sandstone substrate they were on washed away.

Physa gyrina, a coiled shell gastropod that was common in the area, was tested in the laboratory for comparison with the attachment ability of the Zion Snail. In the preliminary plastic channel test, only two snails remained after the initial flow of water. At < 75 mm of flow in the measuring tube, the shells of the remaining snails started to lift from the foot and soon pulled the foot off the channel. No snails remained in the plastic channel after flows of > 75 mm. In the controlled wash experiment, only 2 of 16 and 1 of 12 snails remained at 5 liters and 10 seconds (0.5 l/sec), the lowest flow possible. A third replicate with 12 snails left no snails remaining, and the experiment was stopped.

Within Seep Distribution

The seep-spring area was chosen for the analysis of factors that influence local distributions. Snails were found in 126 of 262 quadrats (48.1%). Using a Chi-square test of independence, snail distribution was found to be independent of slope and algae cover while dependent on depth and flow (Table 3). Flow class 1 (<1 mm) accounted for 125 of the 126 quadrats (99.2%) that contained snails. The proportion of quadrats that contained snails also decreased with increasing water depth. The single quadrat with a snail in high flow (> 1 mm) is not significantly different from 0 (Table 4).

In an attempt to determine the overall effects of the variables and their interactions on snail distribution, the ANOVA model

Y (snails) = D (depth) + V (velocity) + S (slope) + DV + DS + VS +E

was used in weighted least squares analysis in RUMMAGE. Algal cover was not used because it was not significant and the five cover classes were contributing too many missing cells. The data used were from a single sampling date and from a specific area in the seep-spring to minimize effects of unaccounted factors. The three factors plus interactions accounted for 19% of the variation ($R^2 = 0.193$, R^2 adj. for df = 0.101). The terms *water depth* and *velocity* were significant at $p < 0.05$ (Table 5).

TABLE 3. Chi-square analysis of independence to determine the significance of water depth, water flow (velocity), substrate slope, and algal cover in determining the distribution of the Zion Snail in the seep-spring area.

Variable	x^2	df	Significance
Depth*	33.78	2	**
Flow	19.33	1	**
Slope	0.50	2	N. S.
Algae	2.10	4	N. S.

*Depth class 4 was added to 3 since less than five samples were taken at depths greater than 10 mm.
**$p < 0.05$

TABLE 4. Number of quadrats and occurrence of snails within various water depth and flow categories.

Parameter[a] and category		N	# with Snails (% ± 95% C. I.)
Depth[b]	1	142	90 (63.4 ± 7.9)
	2	74	28 (37.8 ± 11.1)
	3	46	8 (17.4 ± 11.0)
Flow	1	239	125 (52.3 ± 6.3)
	2	23	1 (4.3 ± 8.3)[c]

[a]See Table 1 for description.
[b]Depth class 4 was added to 3 since less than five samples were taken at depths greater than 10 mm.
[c]Not significantly different from 0 at $p < 0.05$.

DISCUSSION

The highest population densities were found in Orderville Canyon and the seep-spring. Both areas had densities exceeding $100/m^2$. Early accounts of the snail did not include density estimates; consequently, historic comparisons cannot be made. However, Gregg (1940) described "Fairy Land" 3/4 mi south of Sinawava as a terraced region with numerous snails on horizontal surfaces. From his description and the location, Fairy Land is possibly the seep-spring area we studied. Pilsbry (1926) collected the type specimens at the Narrows mouth and found no Zion Snails above three miles into the Narrows. Because of accessibility, Zion Snails were often collected at the mouth of the Narrows. Woodbury (cited in Chamberlain and Jones 1929: 167) reported that cliffs (seeps) near the type locality and beyond had been "stripped of snails by collectors on previous occasions, but that in a few days migration from above had soon renewed the supply." The migration reported is most likely of snails from higher, inaccessible parts of the seep to the lower regions visited by collectors. Presently, the lower, accessible seeps in the Gateway and the mouth of the Narrows contribute only a small percentage to the total number of Zion Snails in the park.

The distribution of the Zion Snail is patchy. They occur at differing distances in reference to the Virgin River, with various distances between subpopulations. The only snails found in deep water were those in the stream below the waterfall at the seep-spring area. However, density in the stream was very low and most likely was the result of snails being washed down from the seep above.

The silt-laden Virgin River, despite being the physical factor that joins most of the seeps together, may be a barrier to snail movement and contributes to the patchy distribution. The absence of snails in the river's main channel may indicate an avoidance of the silt or an inability to survive there. However, the river may still be a major avenue of dispersal. Some snails in the Narrows occur very close to the river and may be carried downstream during highwater or flooding. These snails are certainly covered during periods of high flow. If the snail can survive in the river for a short period of time, the Narrows may be a source of its origin for downstream areas. The seeps along the Gateway that are presently isolated from the river may have been colonized during extreme flooding or by other vectors. The extreme patchiness may be a reflection of rare colonization events and local extinction.

Within seeps, the snail distribution is patchy. Water depth and velocity are viewed as limiting factors on a gross scale. Snails are found in decreasing frequencies with increasing water depth and are not found at all in areas of high flow (Table 4). However, as shown by the ANOVA model, depth and water velocity only accounted for 10% of the variation when adjusted for df. Even in areas of favorable depth and velocity, much of the distributional variation is unexplained by the measured factors. The localized patchiness may be linked with food sources, variations in water flow, and the movement of snails that were not measured.

As shown by the flow experiments, the Zion Snail is suited for living in water flows much higher than those normally encountered in the seeps. The attachment abilities are also much greater than *Physa gyrina*, which has a

TABLE 5. Results of RUMMAGE ANOVA testing occurrence of snails with environmental variables Depth (D), Flow (F) and Slope (S). (N = 262).

Source	df	ss	MS	F	Significance
D	3	31.70	10.58	4.32	0.006
F	1	24.52	24.52	10.02	0.002
S	2	0.72	0.36	0.15	0.863
DF	2[a]	8.80	4.40	1.80	0.169
DS	6	15.25	2.54	1.04	0.403
FS	2	8.62	4.31	1.76	0.175
Error	141	345.05	2.45		

$R^2 = 0.193$
R^2 adjusted for df = 0.101
[a]df lost due to missing cell.

higher, coiled shell. The early literature (Pilsbry 1926, Woodbury 1929, Chamberlain and Jones 1929) states that the purpose of the limpetlike shell and large foot is to allow the snail to live on the vertical surfaces in the trickling water. However, most snails are not found in visibly moving water and are not restricted to vertical surfaces. Slope was not a significant factor (Table 5), and snails are found on horizontal surfaces.

The hypothesis (Woodbury 1933) that the large foot and reduced spire evolved from a more typical physoid type snail as a result of high flows or floods in the seep environment is probably correct. We feel the selective value of attachment during high flows is quite significant. Seeps near the river are occasionally flooded (Malanson 1978), and the ability to remain attached during floods would be an advantage. Based on the experiments, the higher, coiled shell of a typical snail would have caused it to be washed away even in a minor flood, whereas a majority of the Zion Snails would have remained attached to the seep. The adaptive value to the Zion Snail of a large foot and limpetlike shell is, in our opinion, to remain attached during periods of fast flows and flooding, allowing the snail to remain in and exploit seep habitats.

SUMMARY

This research, along with past studies on the Zion Snail, provides a basic understanding of its general distribution and habitat use. Future studies should be done to determine the distribution further up the Narrows and in Orderville Canyon; the role of temperature in controlling reproduction, food habits, and mortality factors; the role of drying seeps on distribution; and, fiinally, the effect of floods on the Narrows and Orderville Canyon populations. Some of these proposed studies would necessitate collecting adult snails and raising them in the laboratory, but others could only be accomplished after long-term field observations. Lastly, it must be recognized that we know nothing of populations in gardens high up on the canyon wall or if the snail even exists in those gardens.

Although the snail is endemic to Zion National Park, there are no large populations, but the populations we studied contained sufficient numbers for reproduction to take place. The Zion Snail has probably never existed in large numbers and, in comparison to other snails, it may be considered rare.

LITERATURE CITED

CHAMBERLAIN, R. V., AND D. T. JONES. 1929. A descriptive catalog of the Mollusca of Utah. Bulletin of the University of Utah 19: 1–203.

GREGG, W. O. 1940. Mollusca of Zion National Park, Utah. Nautilus 54: 30–32.

MALANSON, G. P. 1978. Distribution of plant species in the hanging gardens of the Narrows, Zion National Park, Utah. Unpublished thesis, University of Utah, Salt Lake City.

PILSBRY, H. A. 1926. A fresh-water snail, *Physa zionis*, living under unusual conditions. Proceedings of the Academy of Natural Sciences of Philadelphia 77: 325–328.

RYAN, T. A., B. L. JOINER, AND B. F. RYAN. 1981. MINITAB, Minitab reference manual. MINITAB Project, Statistics Department, Pennsylvania State University, University Park, Pennsylvania.

SCOTT, D. T., M. W. CARTER, AND G. R. BRYCE. 1982. RUMMAGE. Statistics Department, Brigham Young University, Provo, Utah.

TALMADGE, R. R. 1970. How far ecology? Of Sea and Shore 1: 131.

WELSH, S. L., AND C. A. TOFT. 1981. Biotic communities of hanging gardens in southeastern Utah. National Geographic Society Research Reports 13: 663–681.

WOODBURY, A. M. 1929. The snails of Zion National Park. Nautilus 43: 54–61.

_____. 1933. Biotic relationships of Zion Canyon, Utah, with special reference to succession. Ecological Monographs 3: 147–245.